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Westinghouse Electric Sweden AB

Dismantling Techniques

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Abstract

This report describes different dismantling techniques. In general, the techniques have been selected on the basis of previous experience on international decommissioning and segmentation projects. Most of the reactor decommissioning projects have been completed or are in progress in the USA.

The segmentation of the reactor internals are discussed and given the complex nature of the reactor internal components and their expected levels of radioactivity, it is proposed that more than one cutting process is used during their segmentation. One-piece removal and segmentation of the RPV is discussed. Global experience for the RPV disposal has largely been dependent upon the size and weight of the vessel to be disposed of as radioactive waste and the access to a radioactive waste disposal facility that will accept large components. Besides the dismantling of the reactor internals and vessel other components are also discussed e.g. pipes, ventilation, cables and concrete. The final topic of this report deals with demolition techniques which can be used for both contaminated and non-contaminated buildings.

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0 SUMMARY

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The segmentation of the reactor internals are discussed and given the complex nature of the reactor internal components and their expected levels of radioactivity, it is proposed that more than one cutting process is used during their segmentation. One-piece removal and segmentation of the RPV is discussed. Global experience for the RPV disposal has largely been dependent upon the size and weight of the vessel to be disposed of as radioactive waste and the access to a radioactive waste disposal facility that will accept large components. Besides the dismantling of the reactor internals and vessel other components are also discussed e.g. pipes, ventilation, cables and concrete. The final topic of this report deals with demolition techniques which can be used for both contaminated and non-contaminated.

1 INTRODUCTION AND METHOD

This report was prepared as a part of the concept choice study (KVU) for future decommissioning of the nuclear facilities in Norway. The KVU is conducted by DNV GL with Studsvik, Westinghouse and Samfunns- og Næringslivsforskning (SNF) commissioned by the Ministry of Industry and the Ministry of Fisheries in Norway (NFD).

The KVU will provide a recommendation on the most optimal socio economic level for decommissioning when the facilities in Halden and Kjeller are shut down in the future. In addition the KVU will provide a recommendation on decommissioning strategies and provide input to the decision about how to allocate the total costs.

The Institute for Energy Technology (IFE) has a license for the operation of Norway's two research reactors at Kjeller and in Halden. It is not decided when or if any decommissioning of the nuclear facilities is to take place.

During previous applications for operating licenses IFE has established decommissioning plans that vary somewhat from this study both in regards to scope – what buildings and areas are included - and the way the level of decommissioning is defined.

1.1 PURPOSE

The purpose of this chapter is to provide information on the typical tools and techniques as they are today that could be used during the decommissioning of a nuclear facility. In general, the techniques have been selected on the basis of previous experience on international decommissioning and segmentation projects. Most of the reactor decommissioning projects of this type have been completed or are in progress in the USA. For segmentation of reactor internal parts substantial experience is continuously made from the Nordic plants. In some cases, the chosen technique may not be the same as might be chosen if a similar task were to be performed during a plant refurbishment or upgrade. This is a reflection of the less precise nature of the work and the fact that the plant will not need to be restored to an operational state upon completion, either by reinstatement of equipment or clean-up to the as-operated condition.

1.2 METHOD

The information provided in this chapter is based on international experience from dismantling projects and the philosophy adopted is that only proven existing techniques will be employed. Several of these projects are managed by Westinghouse Electric Company and the experiences from these projects are not publically available. Therefore, the numbers of quoted references are few, supporting the information presented in this chapter.

1.3 SCOPE AND ASSUMPTIONS

It is assumed that, for safety reasons, no significant dismantling work is carried out while fuel remains on-site, e.g. in the fuel storage pools. This is to ensure that there are no inadvertent modifications or system shutdowns that adversely affect the safe storage and management of the fuel. This is possibly a conservative approach, but more investigation work would need to be carried out before it is dismissed.

It is assumed that, as part of the defueling activity, the reactor control rods are removed for storage/disposal. Removal will be carried out using normal plant operational procedures for control rod replacement, i.e. using the Service Bridge and the twist/lift removal operation.

2 BACKGROUND

2.1 PRESENT SITUATION IN NORWAY

Dismantling techniques presented in this chapter are also used in conventional dismantling and demolition in Norway today.

2.2 INTERNATIONAL EXPERIENCE

The techniques presented in this chapter are used in international dismantling and demolitions projects. The main experience from dismantling and demolition techniques comes from USA, where most of the nuclear decommissioning projects have been completed. The segmentation references and experience comes mostly from the Nordic countries, where segmentation projects have been carried out continuously throughout the 21st century.

3 CONCLUSIONS AND RECOMMENDATIONS

The dismantling techniques presented in this chapter are proven techniques, not necessarily used in nuclear industry but in general decommission and dismantling projects. This minimizes the risk for equipment failure and utilizes the existing experience and lessons learned from using the different techniques.

There are four main reasons for decontamination. These are removing contamination to facilitate access to systems and components, minimise the spreading of contaminants (especially in high contaminated areas), reduction of dose for the workers and materials can be characterised as a lower waste class reducing the total amounts of radioactive waste. Since there are many parameters to consider when choosing decontamination method, such as the history of the facility and type of material, the method needs to be site specific. When using decontamination during maintenance it is not favourable to use aggressive techniques in order to prevent damage on systems. In decontamination for decommissioning it is the aggressive methods that are used since no care for the systems function are needed.

Dismantling techniques that are labour intensive or difficult to handle are generally not favourable. Some factors to keep in mind when choosing the right dismantling technique are following: safety, efficiency of the tools, cost efficiency (labour intense techniques gives higher collective dose, higher cost etc), waste minimisation (minimize the production of secondary waste) and feasibility of large scale use. The selection of the technique needs to be based on the object to be dismantled and the contamination level i.e. a thorough investigation of the location is required before a technique is recommended.

4 DISMANTLING TECHNIQUES

Due to the variety of dismantling tasks to be carried out during the decommissioning of the nuclear facility, it is expected that a wide range of dismantling techniques will be employed, each selected for its suitability for the technique in question.

The philosophy adopted within this study is that only proven existing techniques will be employed. This is so that:

- The client can be confident that the technique described is suitable for the task and has already been used for a similar application, generally in the USA where more decommissioning has been completed to date.

In some instances, the most appropriate technique for dismantling an item will be the same technique as was used for maintenance when the plant was operational.

The disassembled pieces would then be segmented for packaging or disposal as appropriate. For other tasks, segmentation or other destructive techniques will be faster and more appropriate given the material and its intended disposal route after removal. Given the wide range of equipment and material to be removed, a range of techniques will be required, each appropriate to the task. The following sections describe suitable techniques for each task or group of tasks.

4.1 IN-SITU DECONTAMINATION

Most reactor decommissioning projects carry out a chemical decontamination of all major coolant systems prior to the start of main dismantling activities. The aim of this activity is to reduce radiation doses in the area of these systems, thereby reducing overall project man-dose in line with ALARA (As Low As Reasonably Achievable) principles.

Chemical decontamination of the major fluid systems using processes such as LOMI (Low Oxidation State Metal Ion) or CITROX (Citric Acid and Oxalic Acid) is often carried out during the operational life of a plant with the aim of reducing radiation dose rates during refuelling and maintenance activities. The processes used after plant shutdown differ from those used operationally in that they are more aggressive, producing decontamination factors (DF) of up to 100 compared to a DF of 10 which is considered adequate for an operational decontamination (though a conservative DF of 10 may be assumed for the purpose of planning a decommissioning decontamination) . The higher decontamination factors are achieved by removing a small layer of the base metal of the circuit inner surface, as well as any corrosion film. Clearly, this would not be acceptable on a plant that had remaining useful life.

Two main competing processes are commercially available to carry out a decontamination of this type, the Electric Power Research Institute (EPRI) Decontamination for Decommissioning (DfD) Process; and the Siemens Chemical Oxidation Reduction Decontamination (CORD)

Process and variations of it. Both have been used on decommissioning projects to the satisfaction of the plant owners. Both are employed on site in a similar manner. However, the two systems are very different chemically, as described in [1] .

No detailed comparison has been made of the full practical capability of the two systems. The nearest is a document commissioned by EPRI comparing the application of the EPRI DfD at Maine Yankee with the application of a variant of the Siemens CORD system known as CORD D UV (CORD Decommissioning Ultra-Violet) at Connecticut Yankee [1]. This comparison is not complete, as the D=Decommissioning part of the CORD process, the part that removes a thin layer of base metal, was not applied due to equipment problems. However, it was judged that an acceptable decontamination factor had been achieved without this part of the process.

A simple comparison of the results of these two projects and the primary circuit decontamination of Big Rock Point and of Barsebäck 1 and 2 [2] is shown in Table 1.

Table 1. Comparison of Key Results from Various Full Circuit Chemical Decontamination Projects [1] and [2].

Plant	Method	Processing Time (days)	Time on Site (days)	Overall DF	Spent ion exchange resin produced (m^3)
Big Rock Point	EPRI DfD	15	~ 63	27	16.4
Maine Yankee	EPRI DfD	20	~ 71	31.5	17.7
Connecticut Yankee	Siemens CORD	25	~ 122	15.9	13.2
Barsebäck 1	Siemens CORD	11		298	5
Barsebäck 2	Siemens CORD	11		93	4

It can be seen in the comparison between the USA plants that the EPRI DfD process achieves a higher DF in a shorter time than CORD but produces a greater volume of Ion Exchange Resin. But compared to the decontaminations project in Barsebäck Plant the DF factor is much lower. The difference between Barsebäck 1 and 2 is due to the fact that Barsebäck 2 has been through a decontamination project before this project. All the internal parts were removed from the Barsebäck 1 and 2 Reactor Vessel. As part of any real decommissioning project there will be other factors that need to be considered before a preferred technique is selected.

The decontamination at Big Rock Point included the Reactor Vessel (with the internals removed), the circulation piping and pumps, the Steam Drum, the Shutdown Cooling System and the Reactor Water Cleanup System.

The actual DF achieved is variable depending on the initial surface contamination level.

Table 2 shows the variation of the DF achieved against the Initial Contact Dose Rate based on experience at Maine Yankee.

Table 2. Average Contact DF by Radiological Significance, Maine Yankee.

Initial Contact Dose Rate	DF
> 10 mSv/h	107.1
5 to 10 mSv/h	169.5
1 to 5 mSv/h	24.5
< 1 mSv/h	5.2

4.2 REACTOR INTERNALS SEGMENTATION

Given the complex nature of the Reactor Internal components and their expected levels of radioactivity, it is proposed that more than one cutting process is used during their segmentation. Each cutting process will be selected on the basis of previous experience and applicability to the various cutting tasks required for successful dismantling.

The radiological condition of the internal components will require that they are segmented remotely underwater, probably in the storage pool. Ease of cutting process deployment and recovery from fault conditions should also be considered in selection of processes.

Thermal techniques are generally faster than mechanical techniques in terms of both cutting and deployment speed and have been the preferred cutting technique for reactor internals segmentation in the USA. They are also non-contact, non-reaction force techniques, which assists their remote deployment as there is no need for bulky reinforcing of deployment systems. This, coupled with the fact that these techniques can cut in any direction (compared to blades which cut only in the direction the blade is facing) makes them highly manoeuvrable and well suited to cutting complex geometric structures.

However, thermal techniques have disadvantages in that the off-gases from the process need to be captured if airborne contamination levels are to be controlled and, more significantly, the off-gases can drive activated cutting debris up to the surface of the water during cutting. For this latter reason, mechanical cutting techniques are typically used in Sweden for segmentation of the reactor internal components.

Abrasive Water Jet Cutting is another technique typically used for segmentation of the higher activity reactor internal components. Abrasive Water Jet Cutting (AWJC) techniques do not drive material to the surface and also have the advantage that they can cut very thick metal sections. However, AWJC is slower than thermal techniques and also requires the introduction of a cutting abrasive material such as garnet, which results in an additional waste stream. In extreme cases the quantity of abrasive material may reach unacceptable levels.

In addition to these techniques, Metal Disintegration Machining will be used to remove bolts where necessary or advantageous, unless the bolts were routinely removed during operation/maintenance in which case they may simply be unbolted. Simple hydraulic shears will also be used to cut any slender sections such as small tubing etc.

While thermal/hydraulic cutting methods have generally been used in the USA, European projects have tended to use mechanical cutting processes. Both these methods are discussed in the following sections.

4.2.1 Thermal / Hydraulic Internals Segmentation Techniques

4.2.1.1 Plasma Arc Cutting System (PAC)

Plasma arc cutting is a process that severs metal by melting a localized area with the heat of a constricted arc and removes the molten material with a high velocity jet of hot, ionized gas issuing from the orifice.

In the early 1950’s, it was discovered that the properties of the open arc, as used in gas tungsten arc welding, could be greatly altered. The arc was constricted by directing it through a water-cooled copper nozzle located between an electrode (cathode) and the work (anode). Instead of diverging into an open arc, such an arc is constricted by the nozzle into a small cross section. This action greatly increases the power density of the arc. Both the arc temperature and the voltage are raised. An arc passing through a constricting nozzle obtains a high velocity and becomes well collimated and intensely hot.

Water-injection plasma arc cutting is a newly developed process for high speed, cutting of virtually all metals from gauge sizes up to 76 mm thick. Unlike conventional plasma cutting that constricts the arc with a water-cooled copper nozzle, the water-injection technique provides arc constriction by radial injecting water uniformly around the arc. The radial impingement of water around the arc provides a higher degree of arc constriction than can be achieved by conventional means. The net result is an extremely hot, high velocity, plasma jet capable of producing excellent cut quality at high cutting speeds.

Nozzle life is longer with the Water-injection process because water cools the nozzle at the point of maximum arc constriction. The protection afforded by the water also allows the entire lower portion of the nozzle to be ceramic. Consequently, double arcing from the nozzle touching the work piece is virtually eliminated.

The plasma system can also be operated in the conventional mode for cutting plate in the 75 to 153 mm thickness range. In this mode of operation, the injection water is used for nozzle cooling only; arc constriction is achieved purely by the nozzle. A gas mixture of 65% argon-35% hydrogen is used instead of nitrogen because it develops a deep penetrating plasma jet ideal for cutting heavy plate.

4.2.1.2 Abrasive Water Jet Cutting System (AWJC)

The abrasive water jet process utilizes an ultra-high pressure intensifier pump that pressurizes water up to 3790 bar, forcing it through a small nozzle, typically 0.76 mm in diameter. This generates a high-velocity water jet stream at speeds of up to 900 m/s. The resulting cutting action can be used as an alternative to conventional machining methods. Abrasive jet cutting has the ability to pierce through thick materials eliminating the need of drilling starter holes.

The AWJC nozzle uses a single sapphire orifice that focuses a high-energy stream of water through the centre of a mixing chamber. Abrasive particles are pulled into the mixing chamber and entrained into the water jet stream where the particles are accelerated to very high velocities. This supersonic slurry is directed through the exit nozzle situated at a small standoff height from the work piece.

A variety of ferrous and non-ferrous materials up to 500 mm thick can be efficiently cut using the AWJC process. Several types of abrasives are used including aluminium oxide, garnet, iron oxide, silicon carbide, and powdered iron.

4.2.1.3 Metal Disintegration Machining (MDM)

Metal Disintegration Machining (MDM) is a spark erosion process commonly used throughout the industry for destructive cutting. Typical applications include broken tool extraction (taps, drills, reamers), metallurgical sample excavation, and stud removal. It has also been used for common machining operations such as die sinking, whole forming, and key slot cutting, however these operations are now more likely to be done by the more precise Electric Discharge Machining (EDM) process. Because of its higher metal removal rates, MDM is still the preferred process over EDM for destructive cutting in most cases.

The MDM process removes metal from a work piece by melting its surface with a series of intermittent electric arcs that are produced by vibrating a charged electrode (negative) against the work piece (positive). Each time the contact is broken a high-energy arc is created. The molten material lifts off the surface and forms minute globules that are rapidly quenched with a coolant that flows in the gap between the electrode and the work piece. The re-solidified material becomes entrained in the coolant and is flushed away.

The electrode is connected to a constant current power supply and is positioned near the work surface with a precision tool slide. A pneumatic ram controlled by a bi-directional solenoid valve actuates the tool slide. The valve is biased in one direction to feed the electrode into the work piece. If the electrode gets stuck and short circuits, the valve reverses and the ram retract the electrode. When the circuit reopens the valve reverses again and the process repeats. In this manner, the electrode traverses its way through the work piece.

The electrode is typically made from graphite and is normally consumed at a much lower rate than the work piece. The variety of electrode shapes that can be produced are almost limitless, however, complex designs tend to wear out quicker and are more costly to manufacture. Therefore, electrodes with simple cylindrical or rectangular shapes are most common.

Porting to allow the coolant to flow through the electrode is often incorporated into the design. Efficient flushing is one of the key parameters of the MDM process. The fine particulate debris generated by the process is collected by the coolant (demineralized water). The debris-laden coolant can be disposed of with other liquid waste or optionally filtered, cooled and recycled. Approximately 13 litres per minute are used during the cutting process. Other parameters that directly affect the process are electrode feed rate, cutting current level, solenoid valve responsiveness, vibrator frequency and amplitude.

MDM is well suited for the cutting of brackets and bolts that are inaccessible to other tooling. Bolts that can't be de-torqued can have the heads burned off to allow component disassembly without cutting. MDM cutting end effectors are relatively simple to manufacture and can be delivered to the work location with long handled tools (poles) and self-mounted by clamping with pneumatic cylinders. MDM is a slow process, with a material removal rate of about 65 millilitres an hour. Therefore, it is best suited for limited destructive cutting applications.

4.2.2 Thermal / Hydraulic Internals Segmentation Equipment

The following sections describe in more detail the equipment expected to be required to allow the 3 main cutting processes (Plasma Arc, Abrasive Water Jet and Metal Disintegration Machining) to be successfully employed on the reactor internals removal project.

4.2.2.1 Control Systems

Work Control Centre - The work control centre is the area where all critical system controls are located. The anticipated location is at or near the reactor operating floor. This area will store the following items: Manipulator Bridge computer controls, Abrasive Water Jet System and Controls, Plasma Arc Cutting System and Controls, MDM Systems and Controls, Water Filtration controls, HEPA System controls, Waste Management Controls, and Underwater Vision System controls and monitors.

Power Distribution Centre - The Power Distribution Centre is where all power conditioning and breakouts will occur. It will consist of all circuit boxes; transformers and un-interruptible power supplies as required by the various segmentation and support systems. This distribution centre will be located as close to the Work Control Centre as practical.

4.2.2.2 Manipulator Bridge

The Manipulator Bridge is the primary tool delivery system used throughout the project. The bridge concept is based on the bridge used by Westinghouse for the San Onofre SONGS-1 Internals Segmentation Project. The bridge will be mounted on the rails running either side of the fuel and reactor pools currently used for the Reactor Service Bridge. A detailed review of the Reactor Service Bridge would be needed to determine if it could be recycled for use as the Manipulator Bridge, though even if it could, the fact that it would need extensive modification and testing away from the reactor pools may make this impractical. Figure 1 shows a similar, shorter span Manipulator Bridge in operation during segmentation of the Yankee Rowe Reactor Internals.

This manipulator has four axes of motion:

- Y- axis: The movement of the gantry bridge along the rails
- X-axis: The trolley assembly that traverses the bridge
- Z-axis: The vertical motion of the mast assembly
- θ-axis: The rotation of the mast about its centre line

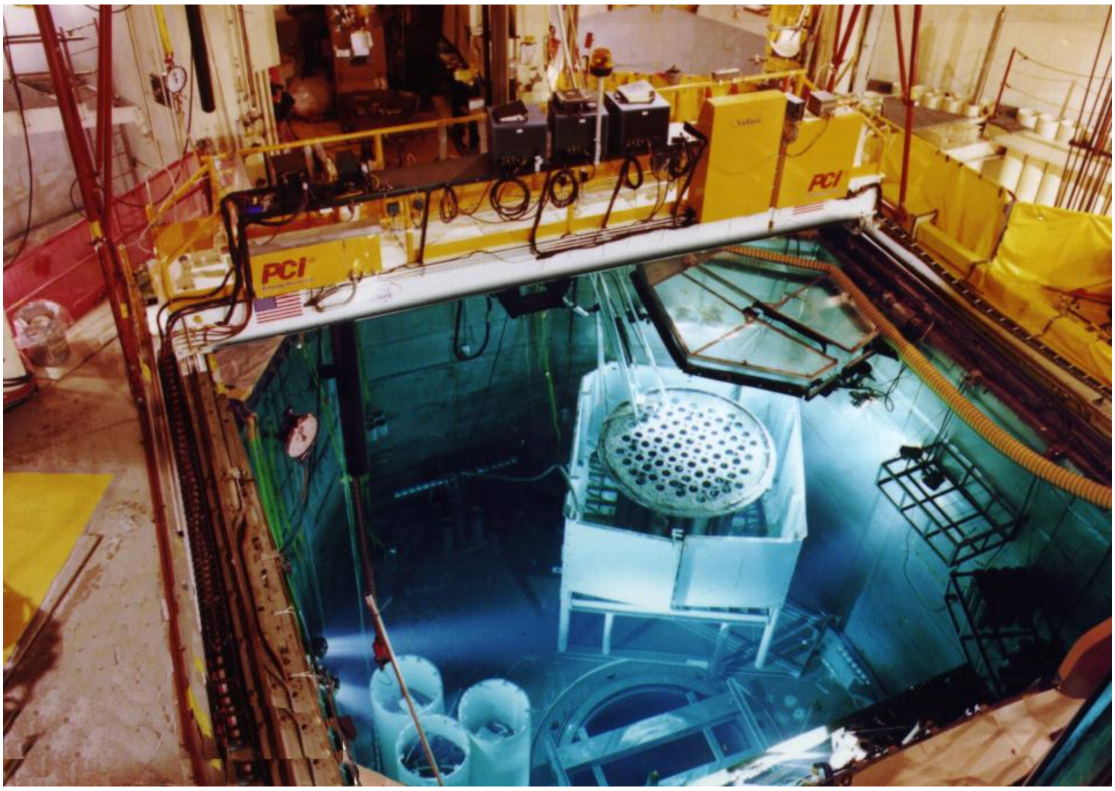

Figure 1.Yankee Rowe flooded Reactor Cavity with Manipulator Bridge running on rails on both sides of the pool and Reactor Internals Segmentation Cubicle sitting on the bottom of the pool (with Upper Internals inside it).

The Manipulator Bridge delivers the Abrasive Water Jet cutting head or Plasma Arc Cutter torch to the components to be segmented. The Manipulator Bridge is capable of linear and circular interpolation; simultaneous multi-axis moves to follow virtually any cut path required. The four (4) axes of motion (X, Y, Z, θ) are controlled by a Computerized Numerical Control

(CNC) System. The computer can execute stored pre-generated programmes or digitize, store, and execute cut paths in the teach/learn mode.

The bridge incorporates a walkway across the entire span of the pool. The walkway allows access over the work piece, and assists the visual sighting or delivery of cutting heads, long handle tooling or specialist rigging. The handrails of the bridge incorporate distribution for de-mineralized water, air/nitrogen and electrical service to accommodate support tooling and rinsing of tooling exiting the pool. This feature has proved convenient and minimizes cables and hoses cluttering the bridge walkway. The bridge also utilizes two cable management carriers, the X-axis on the side of the pool running parallel with the support rails, and the Y-axis mounted directly on the bridge frame. Z-axis cable management is provided by an automated hose/cable reel system that is controlled by the CNC system. These carriers will house the electrical power cables, abrasive water jet supply hoses, gas hoses, de-mineralized water supply lines, vision system cables, etc.

To deliver the cutting end effectors to the required depths, a telescoping mast is used. In the full-up position, the end effectors are approximately 420 mm above the floor of the bridge to allow for quick change of consumables. While raising the mast, an integral rinsing ring surrounding the mast is automatically operated, preventing hot particles from migrating to the bridge.

25 mm thick steel deck plates are used over the bridge walkway to provide radiation shielding for the bridge technicians. A shelf is erected on the back handrail to support the vision system monitors and camera controllers. This creates a convenient monitoring area while manipulating long handled tools from the bridge.

4.2.2.3 Abrasive Water Jet Cutting System

A typical abrasive water jet cutting system is an industrial duty unit manufactured by Jet Edge, Inc. of Minneapolis, MN, USA, though other systems are available. The system can be custom configured, integrated with controls, hoses and cutting head mounting into the overall cutting system. The Jet Edge Model 55-100 is shown in Figure 2.

Figure 2. Jet Edge Model 55-100 Intensifier Pump and OmniJet Abrasive Cutting Head.

Table 3 provides information regarding an Abrasive Water Jet Cutting system from Jet Edge.

Table 3. Information regarding Jet Edge Inc AWJ Cutting System.

Item	**Jet Edge Inc. AWJ Cutting System – based on Model 55-100B Intensifier Pump**
Capacity	Cuts metals up to 510 mm thick Highly variable cutting rates depending on material and quality of cut but typically for steels: 13 mm thick – 330 mm/min 38 mm thick – 91 mm/min 76 mm thick – 40 mm/min
Secondary Wastes	Metal and abrasive fines suspended in water

4.2.2.4 Plasma Arc Cutting (PAC) System

The plasma arc cutting system used for SONGS-1 was a Hypertherm TM Model PAC-500 specially configured for underwater applications. The system is capable of both water-injection plasma arc cutting and conventional plasma arc cutting.

Water-injection plasma cutting is a process developed for high speed-high quality cutting of virtually all metals from gauge sizes up to 75 mm thick. Unlike conventional plasma cutting, which constricts the arc with a water-cooled copper nozzle, the water-injection process provides arc constriction by radially injecting water uniformly around the arc. The radial impingement of water around the arc provides a higher degree of arc constriction than can be achieved by conventional means. The net result is an extremely hot, high velocity, plasma jet capable of producing excellent cut quality at high cutting speeds.

Nozzle life is longer with the water-injection process because the water cools the nozzle at the point of maximum arc constriction. The protection afforded by the water also allows the entire lower portion of the nozzle to be ceramic. Consequently, double arcing from the nozzle touching the work piece is virtually eliminated.

The PAC-500 system can also be operated in conventional mode for cutting plate in the 75 – 150 mm thickness range. In this mode of operation, the injection water is used for nozzle cooling only; arc constriction is achieved purely by the copper nozzle. A gas mixture of 65% argon-35% hydrogen is used instead of nitrogen because it develops a deep penetrating plasma jet ideal for cutting heavy plate.

The plasma arc cutting system consists of two 750-amp master/slave power supplies, a water chillier and control console. The system is capable of cutting stainless steel up to 150 mm thick, at a water depth of 15.25 m. various shaped and sized torch end effectors are included for accessing the intricate geometry of the reactor internals.

4.2.2.5 Metal Disintegration Machining (MDM) Equipment

<u>MDM Power Supplies -</u> The MDM power supplies used at SONGS-1 were Cammann Model C-45 Metal Disintegrators. Three units were used. These 200 amp systems can be used individually or connected in parallel for high output applications. Each unit includes an integral control pendant and a high-pressure booster pump that provides flush water to the electrode. All required cabling and ground clamps are also included. A variety of special purpose MDM end effectors will need to be developed for the project to suit each particular operation. These will need to be modular in design so that many parts are interchangeable, and so they can be assembled in several different configurations. Table 4 provides information regarding an MDM Machining System from Cammann.

Table 4. Information regarding Cammann Inc. MDM Machining System.

Item	**Cammann Inc. MDM Machining System - based on Cammann Model C-45 MDM Power Supply**
Capacity	Highly variable cutting rates depending on material and quality of cut but typically for steels: Removes 100 mm of 50 mm diameter stud in 1 hour Removes 200 mm of 100 mm diameter stud in 6.5 hours
Secondary Wastes	Metal and graphite electrode fines suspended in water

4.2.2.6 Hydraulic Shears

For cutting long slender items such as bars or tubing metal cutting shears will be used. These hydraulically powered shears will have the capacity to cut up to 25 mm thick diameter steel solid bar or 65 mm diameter heavy wall tubing. Round or rectangular cross-sections can be cut. Deployed using long-handled tools, the shears will be designed to fit into tightly constrained areas and be easily manipulated. Shears will be used wherever practical since their operation results in no cutting debris.

4.2.2.7 Specialised Rigging, Material Handling Equipment and Storage Stands

A variety of special lifting and support equipment will be required for the project. All devices carrying heavy loads will need to be analysed for adequacy using engineering calculations and finite element modelling as required. Typically these structures will be welded frames made from structural steel or stainless steel. All design and construction is completed in accordance with applicable codes and standards.

All carbon steel structures should be painted with an acceptable alkyd enamel paint to resist corrosion.

<u>Temporary Material Holding Stands -</u> Various staging and holding fixtures will be required throughout the project to support pieces during cutting or to temporarily stage them until they can be moved to their final packaging location.

<u>Clamping and Gripping Devices -</u> The project will require handling equipment necessary to move segmented components from the cutting location to the waste containers. This equipment will consist of standard plate clamps, lifting hooks, straps and cable assemblies. Additionally, unique designs of tooling necessary to handle any component unique in shape and size not covered by standard clamping devices will be required.

Long Handle Tools - Long Handle Tools (LHTs) will also be included with the handling tools. These poles will mount various grippers and special hooks to aid the manipulation of parts underwater. The design should make use of modular components that can be easily interchanged to make up the desired tooling configuration.

Lifting Cables and Slings - Rigging equipment used will be selected to minimize the collection of radioactive particles. Each sling will have a working load rating label attached.

4.2.2.8 Contamination Control Confinements

A primary goal is to maintain the water in the reactor and internals pools clear and free from radioactive debris. To accomplish this, the volume of water affected by cutting is minimized where possible and cutting debris is captured as close to the source of generation as possible.

Segmentation Cubicle - The Segmentation Cubicle is the fixture where most cutting activities will occur. This cubicle will be designed to support the heaviest internals assembly. The cubicle will have a base capable of distributing floor loads within allowable limits of the RPV cavity floor. The cubicle will have walls that attach to the base and extend above the surface of the water. The walls will be designed for maximum reliability and ease of replacement if required. One side of the cubicle will have a remotely actuated door to allow easy transfer of segmented pieces to the waste containers. By reducing the amount of water to be processed after cutting, water clarity will be readily restored.

Additionally, the Segmentation Cubicle will incorporate an open grid support plate that allows cutting debris to fall through the grid and into a compartmentalized hopper system. Suction flow through each hopper quadrant can be independently regulated to maximize debris entrainment across the grid area where cutting is taking place. The hopper outlets connect to a central manifold under the table that connects directly to the water filtration system. Check valves located on the Segmentation Cubicle upper walls allow clean water to enter the confinement. The resultant flow is downward, keeping contaminated debris shielded by the entering layer of clean water, which helps maintain dose levels at the water surface ALARA.

Local Collection Hoods - Each cutting tool will have a local enclosure to collect entrained debris. A hose connection point is provided on the enclosure to connect to the water filtration system. These enclosures are designed such that they do not interfere with the installation of the tool and maximize the amount of debris collected. Some applications require more coverage than others, primarily because of the amount of debris to be created by the cut.

4.2.2.9 Video Monitoring System and Lighting

The Underwater Vision System will consist of the underwater lights and cameras necessary to monitor the cutting process and positioning of the cutting equipment.

General area lights will be positioned around the pools to accommodate support activities such as filter change outs, segment and liner transfers. These lights will hang off the edge of the refuelling floor and should not extend above that elevation. Specific area lights will be positioned as needed. All lights should be long life, high lumen models to reduce the frequency of bulb changes.

For camera support, the vision system will utilize underwater, radiation tolerant cameras. These are configured as end effectors mounted to pan and tilt units on auxiliary vertical mast assemblies.

The camera units will have remote focus and zoom (magnify) capabilities and include slim-line and 90° mirrors for ease of access into low clearance areas.

A remote console is used to house the video monitors, camera controls, lighting controls, and videocassette recorder used to monitor and record the cutting and handling operations.

4.2.2.10 Water Filtration System

The purpose of the water filtration system is three fold; first the system must maintain water clarity during refuelling cavity segmentation activities; next, it must maintain a low concentration of insoluble and soluble radio nuclides in the reactor cavity water to keep dose levels ALARA; and lastly, the waste produced by the system must be in a form and concentration that is acceptable for disposal.

Water clarity will be maintained through the use of a solid separation system comprised of dual cyclone separators followed by three banks of back washable 1-micrometer filters. A slipstream from the filter will be routed through an absorber/demineralizer for soluble radionuclide removal and chemistry control. Purified water will be directed back to the reactor pool.

Waste generated by the proposed system will consist of AWJC grit/metal fines and PAC dross resulting from cutting operations, ion exchange resin, granular activated carbon, and filter cartridges. All waste will be transferred to disposal containers and dewatered in accordance with the waste acceptance criteria prior to transport and disposal.

4.2.2.11 Off-gas Collection/Filtration System

The purpose of the off-gas collection system is to assure that potentially contaminated gases related to the segmentation process do not escape from the reactor cavity into the containment atmosphere. A hood is suspended above the water and is positioned above the material being cut to capture rising gases. Additional hoods and ducting can also be provided if the piece geometry mandates multiple gas collection points.

An exhaust hood with an open end is positioned over the work area. With this arrangement, clean air is pulled into the hood and across the cutting area. The fumes are pulled through the hood into flexible ducting connected to two redundant High Efficiency Particulate Air (HEPA) filtration systems. The redundancy allows for continuous operation during routine maintenance of either system.

Each filtration unit will consist of roughing filter housing, and a HEPA filter unit which includes a pre-filter, HEPA filter and fan/motor.

The roughing filter housing will be capable of holding multiple banks of roughing filters. Filters of varying filtering efficiency can be installed. This allows the unit to be tailored to changing cutting conditions. These filters are relatively inexpensive and are easily compacted. These features lower disposal costs and exposure.

Completing the system is a HEPA filter unit. During the design and testing phase, the segmentation/filtration contractor will need to work with plant staff responsible for radiation control and waste disposal to determine HEPA replacement criteria to minimize disposal costs. Personnel will be trained in proper change out methods and, if necessary, simple tools can be fabricated so that the filters do not have to be handled directly. Temporary shielding can also be added to the units to minimize exposure.

4.2.3 Mechanical Techniques

As an alternative to the thermal/AWJC techniques described above, a predominantly mechanical cutting methodology can be adopted, as was the case for the BR-3 (Belgium Reactor 3) PWR decommissioning project in Belgium, a number of mid-life BWR reactor internals segmentation projects in Sweden and Finland and for the José Cabrera PWR internals and RPV segmentation in Spain.

Mechanical cutting has a number of general advantages over thermal/AWJC techniques. It produces no fumes and requires no cutting or fuel gas, both of which can bring radioactive material to the water surface resulting in the need to provide local ventilation at the water surface. Any secondary wastes produced are in the form of spent cutting blades, of which relatively few should be required and cutting swarf (metal filings or shavings removed by a cutting tool) which will be in relatively large pieces which are easily collected. These larger pieces of cutting debris have less potential to disperse through the Reactor Pool water than is the case for thermal/AWJC debris, thereby reducing the potential for spread of contamination and reduction in visibility.

This reduction in visibility can have an adverse effect on the project programme if steps are not taken to manage waste arising, as time will be lost while water clarity is restored to allow segmentation to continue. The thermal/AWJC segmentation methodology described in this report includes the use of local containment measures, such as the use of a segmentation cubicle (see Section 4.2.2.8) to help prevent this occurring and causing a problem. These measures have been used on recent thermal segmentation projects and have proved successful in preventing the visibility problems that occurred on earlier projects. However, if mechanical segmentation techniques are used, the requirement for such local containments may be reduced or even become unnecessary.

The thermal and AWJC techniques described in Section 4.2.1 make use of commercially available tools, though deployed via a purpose built deployment system. In the case of mechanical cutting tools it is more likely that custom built tools as well as the deployment system will be required, though it is noted that these tools employ relatively simple technology that should mean they are easy and cheap to produce and easy to use.

As in the case of thermal techniques, it is expected that a range of techniques and tools will be required to suit the particular task. These are discussed below.

4.2.4 Mechanical Internals Segmentation Techniques

The two main mechanical segmentation techniques used are shearing and sawing.

Shearing has the significant advantage that it produces no secondary wastes in the form of swarf or other cutting debris. The only secondary wastes likely to be produced are spent blades (though blade wear rates are typically low so the blades will not need to be replaced often) and possibly the shear tool itself upon completion of the project (if it cannot be decontaminated).

Shears are generally hydraulically powered and their cutting capacity varies with the design, though the ability to cut solid bar of up to 25 mm diameter or 65 mm diameter heavy wall tubing would be typical. Round or rectangular cross-sections can be cut.

Sawing techniques employ two main types of saw; circular saws and band saws. Both have been used on internals segmentation projects though the band saw appears to have greater flexibility as it is easier to deploy, has a greater cutting speed and produces less swarf than the circular saw.

4.2.5 Mechanical Internals Segmentation Equipment

4.2.5.1 Shear Tools

For cutting of long, slender items such as bars or tubing and for the cutting of the relatively thin sections of core support grids, sawing is not required as these sections can be cut with hydraulic shears. The main advantage of using shears in this situation is that they produce no secondary wastes during the cut. The shears will be designed specifically for the task to be performed to ensure that the cut is clean in every case and to ensure that the shear is easy to locate on each of the various pieces to be cut.

Figure 3 and Figure 4 shows a hydraulic shear being used to cut the Core Spray. This shear has been designed specifically for cutting the 8 mm thick plate sections making up the grid. The tool was operated by two people and used to make around 340 cuts in the grid to the remove the grid structure itself leaving only the outer ring of the support grid, which was subsequently cut using a band saw.

The light shearing tool, with a weight of 40 kg, is a standard tool from the sub-supplier Nike Hydraulics. The connection in the top is designed by Westinghouse. The tool cuts pipes with a maximum dimension of 90×2.5 mm and flat bars with dimensions of 100×8 mm. The three different types of cutting blade can easily be replaced. The cutting force at 700 bar is about 314 kN. Other similar tools will be required for cutting bars, tubing and other sections of the internals.

The heavy shearing tool is used for tubes and flat bars with larger dimensions. The tool that weighs about 210 kg has been tested and used for cutting highly neutron radiated pipes with dimensions of 120×4 mm and flats bar of dimensions 130×10 mm. Because of the expensive cutting blades the tool maximum capacity has not been fully tested. An estimate is that tubes of dimensions 130×5 mm and flat bar of 140×12 mm, in material AISI 304 (stainless steel), neutron radiated, could be cut by this tool. The tool has been used to cut flat bars and tubes on two complete core sprays without the need for replacement of the cutting blades. The cutting force at 800 bar is about 1 000 kN.

Hydraulic shears were also used to segment reactor internals at the BR-3 PWR decommissioning project in Belgium, where it was found that it was possible to use them as long handled tools at distances of up to 7 m.

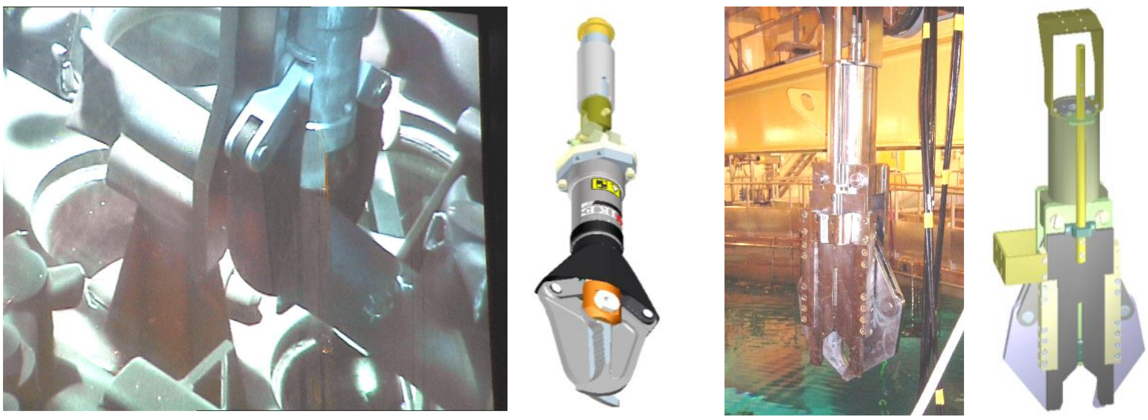

Figure 3. Shearing tools used to cut the core spray system and flat bars on the core grid.

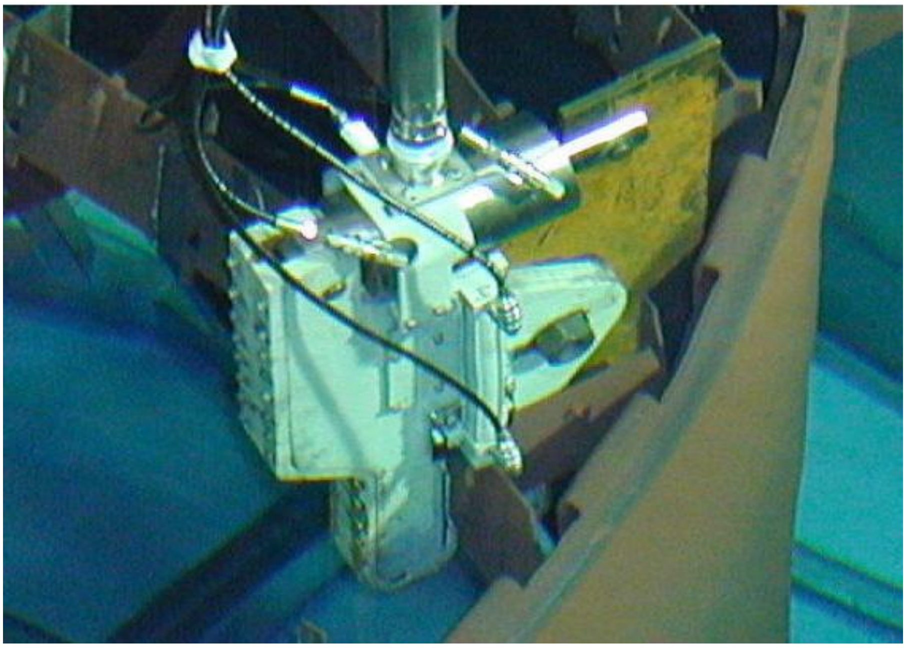

Figure 4. Hydraulic Shears being used for cutting of the Core Grid removed from the Forsmark Nuclear Power Plant.

4.2.5.2 Saws

For the more extensive and complex cutting operations, saws will be used. Two main types are available; band saws (as used on the Forsmark internals in Sweden) and circular saws (which were used for horizontal cuts at BR-3 in Belgium; the vertical cuts being made with a band saw).

<u>Band Saws</u>

The band saws used at both Forsmark and BR-3 were of generally similar design as can be seen in Figure 5. Both saws consisted of a 3 sided square steel framework (the fourth side being left open) with 4 rollers, one on each corner of the framework. The saw is fed around these rollers and in both designs passes through blade guides on either side of the open side of the framework. The blade guides are adjustable to provide pre-tension of the saw blade and can also be rotated to allow the blade to be rotated through 90° at the cutting position, which allows the saw to make vertical cuts as well as horizontal cuts. For those operations where the saw was required to change from vertical to horizontal cutting while the blade was in the work piece, a suitably sized hole was made beforehand using an MDM machine (see Section 4.2.1.3), the change of blade angle being made while the blade was in this hole. The dimensions of the frame in each design dictated the maximum size of each removed piece.

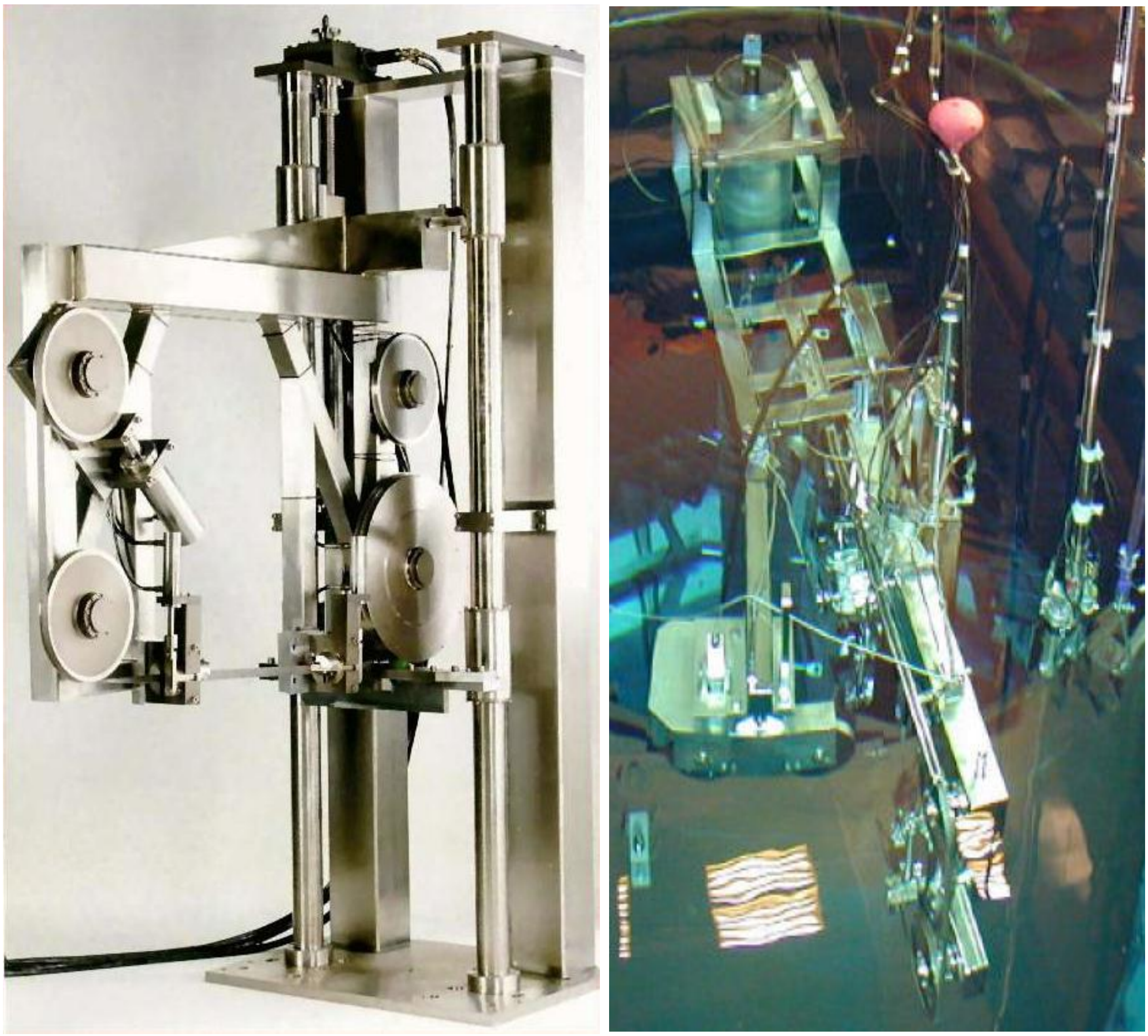

Figure 5. Manufacturers photograph of the BR-3 Band Saw (left) and the Forsmark Band Saw being used to segment the Core Shroud (or Moderator Tank).

The most significant difference between the two band saws used on these projects was the deployment method, the Forsmark saw being mounted on a rotating arm and used to cut a fixed work piece, while the BR-3 saw was held in a fixed position and cut a work piece which rotated on a turntable.

Cutting speed naturally varies with the thickness of the material being cut. BR-3 reported speeds varying from 0.005 m/min for cutting of 200 mm thick sections, up to around 0.04 m/min for cutting of 1.65 mm sections. This is less than one tenth of the speed that can be achieved on similar sections using Plasma Arc Cutters, though the overall production rate, once time for preparation and waste management is considered, may show a lesser difference. The cutting is about 15-25 % of the total time for the whole segmentation project on site.

Circular Saw

Circular saws were used at BR-3, Forsmark and TVO to carry out horizontal cuts. The saw itself was mounted on a fixed extension to a turntable. The work piece to be cut was mounted on the turntable and rotated during the cut. The saw itself could be moved up/down to enable cuts to be made at the correct location. It could also move in/out to cut deeper into the work piece. The cutting tools that Westinghouse is using are based on equipment from Braun. One example is their wall saw, a BWS 15, with rail and clamps mounted to a fasting frame, designed by Westinghouse. Depending on the situation for the actual internal the fastening frame design has to be different. A Braun BTS 8 cutting machine has also been used.

Westinghouse has used disc saw cutting in the TVO segmentation in 2005 and the results were good, see Figure 6. Substantial testing has been performed since then and for the segmentation in Forsmark in 2010-2012 disc cutting has been the chosen technique for cutting of steam dryers. Disc sawing will also be used for some cuts on the core shroud head and almost all cuts on the core spray support frame.

Various sizes of blades can be used, as dictated by the cut. A maximum cut depth of 230 mm is achievable using the larger diameter (660 mm) blade, though the maximum cut in any single pass is 25-30 mm. For thinner sections, the cutting speed is similar to that for the band saw, but is slower by comparison for thicker sections. It is also noted that the circular saw produces more secondary wastes than the band saw as a thicker blade is required (6 mm compared to 2 mm). Experience from segmentation projects in Swedish Plants shows that the circular saw normally has a cutting speed of 1-200 mm/min for 10 mm plates and 1-25 mm/min for 50 mm plates.

The cutting or reaction force required for the circular saw is ~7 500 Nm compared to ~800 Nm for the band saw. This may be of significance during deployment of the saws for some cuts as the band saw is likely to require a less rigid deployment system which may allow a more versatile deployment system to be developed.

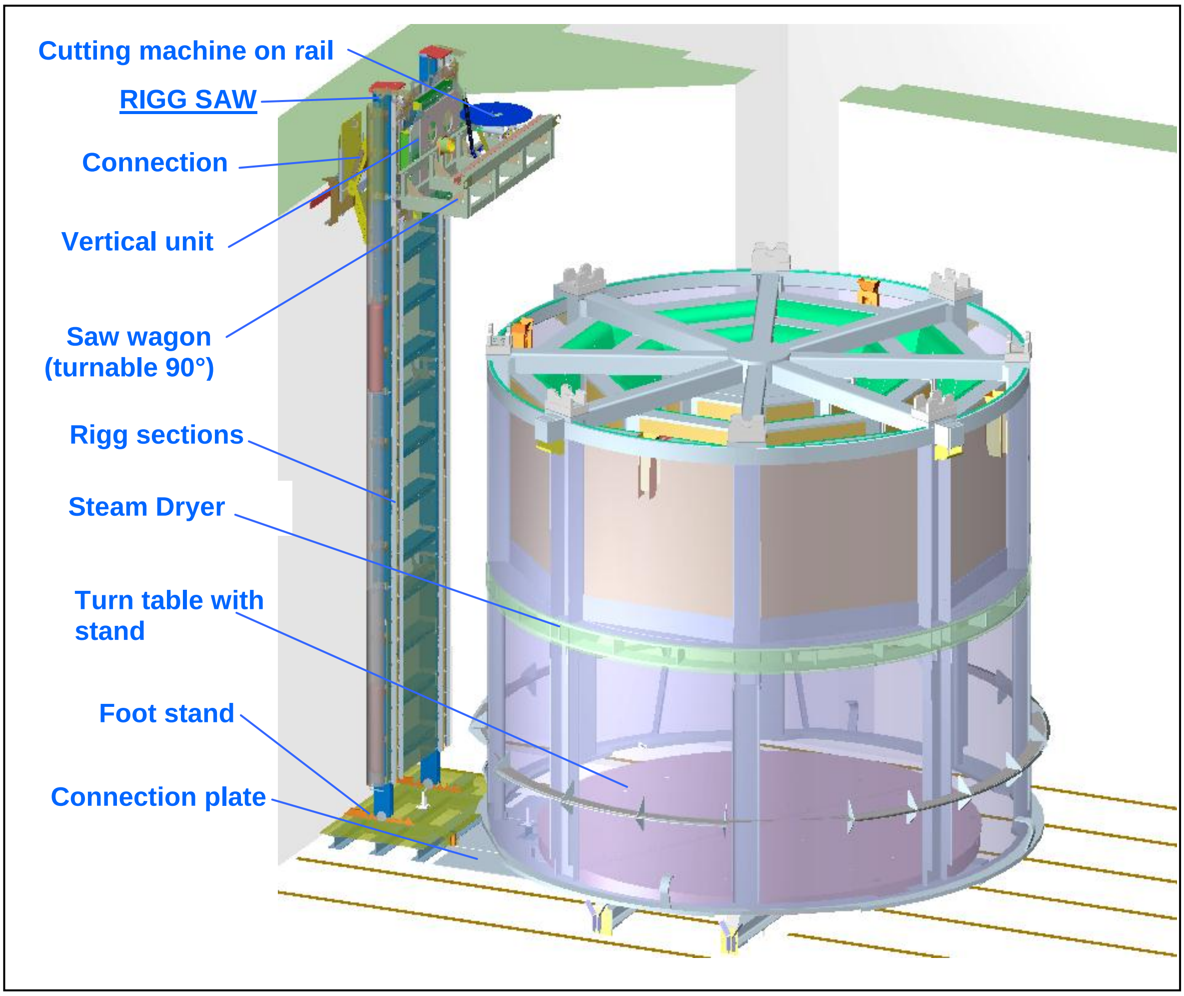

Figure 6. Rig saw with a disc saw mounted to cut the Steam Dryer.

The tube cutter

The tube cutter in Figure 7 is used to cut the steam separator tubes on the core shroud head (CSH). The tube cutter is inserted in to the tube and cuts from the inside and out at a specific level above the CSH spherical surface. To fit different dimensions of tubes some parts can be replaced. All power for clamping to the tube, rotation and forcing out the cutting wheel are done hydraulically. The development and design are done by Westinghouse.

The CSH tube with an outside diameter of 280 mm, thickness of 5 mm is cut in about 20 min. The cutting wheel is normally replaced after 4-6 cuttings.

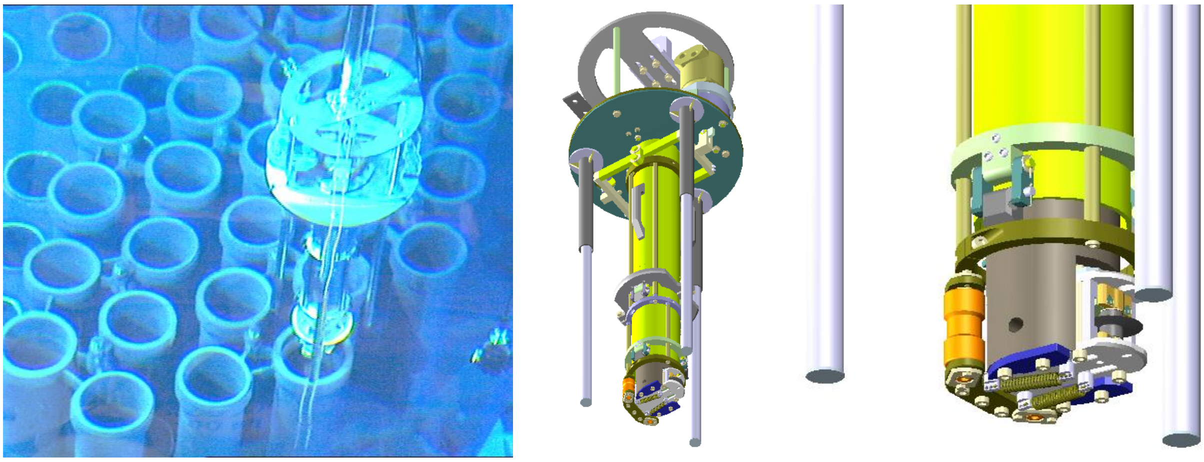

Figure 7. The tube cutter is positioned above the CSH piping. 3D-model views of the tube Cutter.

Other Tools

As well as the shears and saws, which would carry out the main cutting operations in a mechanical segmentation strategy, other smaller tools will be required for specialist tasks.

The BR-3 project made some use of a pneumatically driven reciprocating saw which was fastened at only one end of the blade. This has a significant advantage over the band saw for certain particular tasks in that it only needs access to one side of the work piece. As with the circular and band saws used on this project, the reciprocating saw was a purpose built piece of equipment.

MDM machines (see Section 4.2.1.3) and drills may be required to make starter holes for cutting operations, or holes to allow the band saw to change cutting direction. In addition, MDM may be used to remove bolts, particularly those that have been welded in place, to allow the internals to be split into pieces for easier segmentation.

The existing tools for reactor servicing will also be used for disassembly of the reactor internals in the same way as is carried out during operational maintenance.

Other equipment in the form of support stands, specialist slings and rigging, grabs etc. may also be required. In general this equipment will be similar to that required if thermal segmentation techniques are used.

4.3 REACTOR PRESSURE VESSEL

Global experience for the reactor pressure vessel (RPV) disposal has largely been dependent upon the size and weight of the vessel to be disposed of as radioactive waste and the access to a radioactive waste disposal facility that will accept large components.

In the USA, most large reactor vessels, such as Big Rock Point, Yankee Rowe, Maine Yankee and Trojan, have been qualified as their own shipping containers and were therefore not segmented and packaged for disposal. Where segmentation has been carried out there are two main techniques that seem to be favourable; thermal or mechanical cutting.

4.3.1 One-Piece Removal of the RPV

The study [3] describes how the vessel can be taken out from the building with help of a crane. The fuel, all of the internal parts and the water are first removed from the vessel. The crane is a Mammoet MSG 80 with a capacity of 1 200 tonnes, see Figure 8. The crane is placed on a rail and can rotate 360°. The lifting speed is approximately 10 m/h. The force to the ground can be up to 50 tonne/m^2 and therefore it is necessary to reinforce the ground.

To make the RPV reachable for the crane there must be an opening at the top of the reactor building. The lifting device will be attached to the RPV before the RPV will be released from the suspension device which holds the RPV in place in the building. The dismantling techniques will be the same as for the segmentation. A protection against radiation will be placed around the RPV before it is removed from the building.

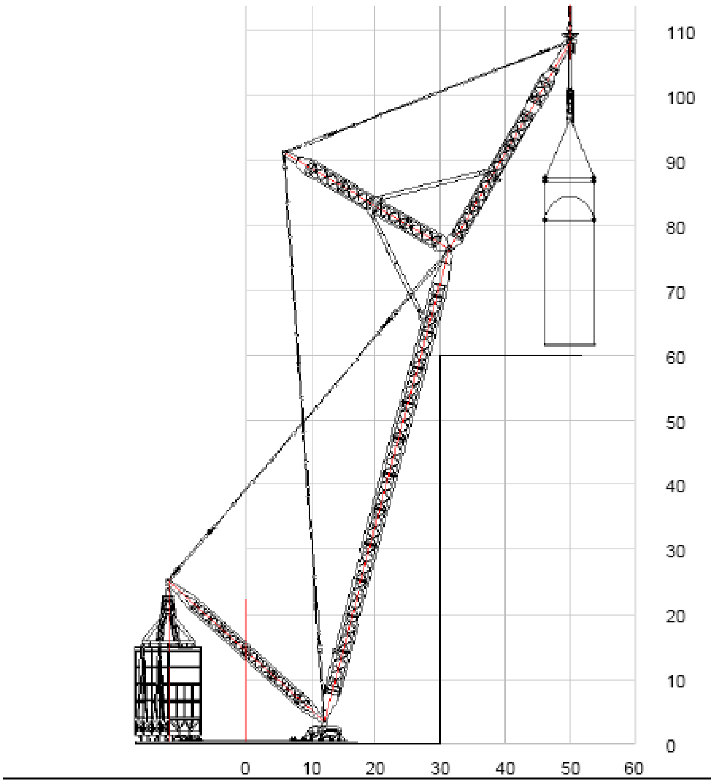

Figure 8. Lift of a RPV with a Mammoet MSG 80.

4.3.2 Reactor Pressure Vessel Segmentation

4.3.2.1 Thermal Cutting

Due to the typical thickness of a reactor pressure vessel the thermal cutting technique most likely to be used is oxy-fuel cutting (OFC) rather than Plasma Arc Cutting.

The oxy-fuel gas cutting processes severs or removes metal by the chemical reaction of oxygen with the metal at elevated temperatures. A flame of fuel gas burning in oxygen maintains the necessary temperature.

The process has been called various other names, such as burning, flame cutting, and flame machining. The oxygen stream performs the actual cutting operation. The oxygen-fuel gas flame is the mechanism used to raise the base metal to an acceptable preheat temperature range and to maintain the cutting operation.

The OFC torch is a versatile tool that can be readily taken to the work site. It is used to cut plates up to 500 mm thick. Because the cutting oxygen jet has a 360° cutting edge, it provides a rapid means of cutting both straight edges and curved shapes to required dimensions without expensive handling equipment. Cutting direction can be continuously changed during operation.

The oxy-fuel gas cutting process employs a torch with a tip (nozzle). The functions of the torch are to produce preheat flames by mixing the gas and the oxygen in the correct proportions and to supply a concentrated stream of high-purity oxygen to the reaction zone. The oxygen oxidizes the hot metal and also blows the molten reaction products from the joint. The cutting torch mixes the fuel and oxygen for the preheating flames and aims the oxygen jet into the cut. The torch cutting tip contains a number of preheat flame ports and a centre passage for the cutting oxygen.

The preheat flames are used to heat the metal to a temperature where it will react with the cutting oxygen. The oxygen jet rapidly oxidizes most of the metal in a narrow section to make the cut. Metal oxides and molten metal are expelled from the cut by the kinetic energy of the oxygen stream. Moving the torch across the work piece at a suitable rate produces a continuous cutting action. The torch may be moved manually or by a mechanized carriage.

If necessary, metal powder can be injected into the cutting torch to further increase the thickness of metal that can be cut, though this does significantly increase the production of cutting debris.

The following Table 5 shows typical cutting speeds that might be achieved using oxy-propane cutters.

Table 5. Variation of typical Oxy-propane cutting speed with material thickness.

Plate thickness mm	**Approximately cutting speed mm/min**
6	430
13	360
25	280
50	200
75	200
100	150
150	130
200	100

The advantages of thermal cutting include:

- Thermal segmentation is significantly faster than mechanical cutting.
- The number of moving parts is minimized, resulting in fewer parts that need replacing due to wear. Maintenance on cutting tips is typically performed by removing the tools from the high radiation areas for replacement.
- The cutting arrangement is flexible and is not required to be rigid. Either the cutting equipment or the material to be segmented can be rotated or remotely controlled to perform the segmentation.

The disadvantages of thermal cutting include:

- As an oxy-fuel supply is used, thermal cutting presents a higher risk for fire and requires additional monitoring and controls.

- Thermal segmentation of radioactive components in air creates airborne radioactivity, which requires the use of HEPA filtration ventilation and containment systems.

Oxy-fuel cutting was used to segment the Reactor Vessel at WAGR in the UK. The fumes created by the cutting process have not been reported as causing significant problems.

4.3.2.2 Mechanical Cutting

As an alternative to thermal cutting, the Reactor Vessel can be cut using mechanical cutters. Mechanical techniques, in particular the use of circular and band saws, were used to segment the BR-3 PWR Reactor Vessel in Belgium. In this case, the horizontal cutting was completed with a circular saw, with the vertical cuts being made with a band saw. The RPV at José Cabrera in Spain is currently being cut with mechanical techniques by Westinghouse. There is also a mechanical cutting project of the Chooz A RPV in France in preparation that will start in a few years. A model of the mechanical cutting of the José Cabrera RPV is showed in Figure 9.

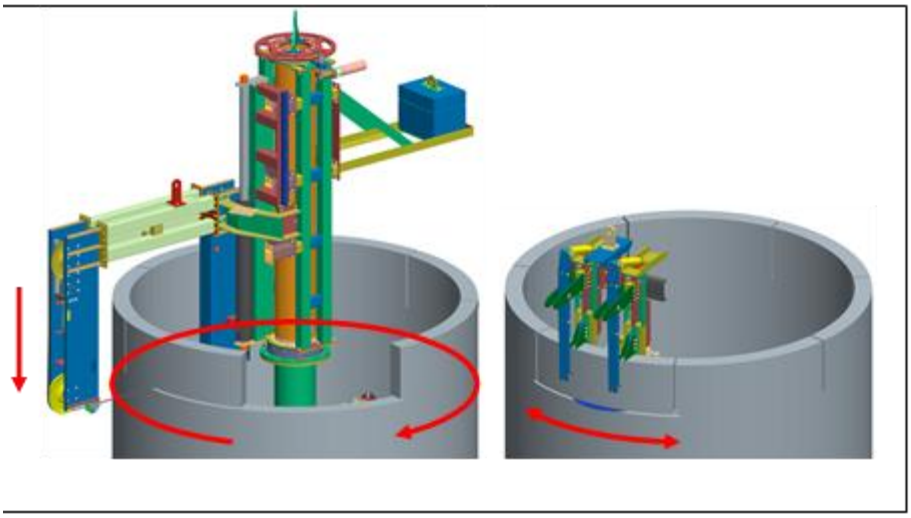

Figure 9. Model of the mechanical cutting of the RPV at José Cabrera.

The circular saws at BR-3 cut from outside the vessel and some problems were identified during testing as the support frame was originally too weak to handle the reaction forces generated. Given the size of the Reactor Vessel and the fact that access from inside the vessel will be easier than from outside, it is envisaged that a frame would be constructed which supported two saws at 180° to each other. These would cut the vessel at two locations at a time and would enable the two saws to react against each other.

The advantages/disadvantages of mechanical cutting techniques are generally the converse of those listed above for thermal cutting. The major advantage is the lack of any fume production, which has potential benefits in terms of airborne contamination. If cutting of the Reactor Internals using mechanical means is preferred for this reason, then the same argument is likely to apply to the Reactor Vessel itself. It may even allow the same tool to be used for both, if a design that accommodates the constraints of both tasks can be produced.

The most obvious disadvantage is the cutting speed. The BR-3 vessel was 114 mm thick over most of its section, with a thicker 356 mm section at the flange and a 63 mm thickness at the bottom dome. Segmentation was carried out under water, which lead to visibility problems and may partially explain the low cutting speeds achieved.

The horizontal circular saw cuts were made at speeds varying between 21 and 41 mm per minute. The vertical cuts using the band saw were made at between 4.7 and 22 mm per minute. In terms of actual time spent, the actual cutting took 154 shifts.

4.4 LARGE DIAMETER PIPE WORK

A number of techniques are available for segmentation of large diameter pipe work. The preferred technique will generally be selected on the basis of the radiological condition of the pipe to be cut and the working area around it.

For higher dose rate areas it is generally preferable to use techniques that can be quickly set up on the pipe and then remotely operated by the decommissioning personnel from a lower dose rate area. A number of these “non-contact” techniques are available. For lower dose rate working areas contact working methods are acceptable.

4.4.1 Clam Shell Pipe Cutter

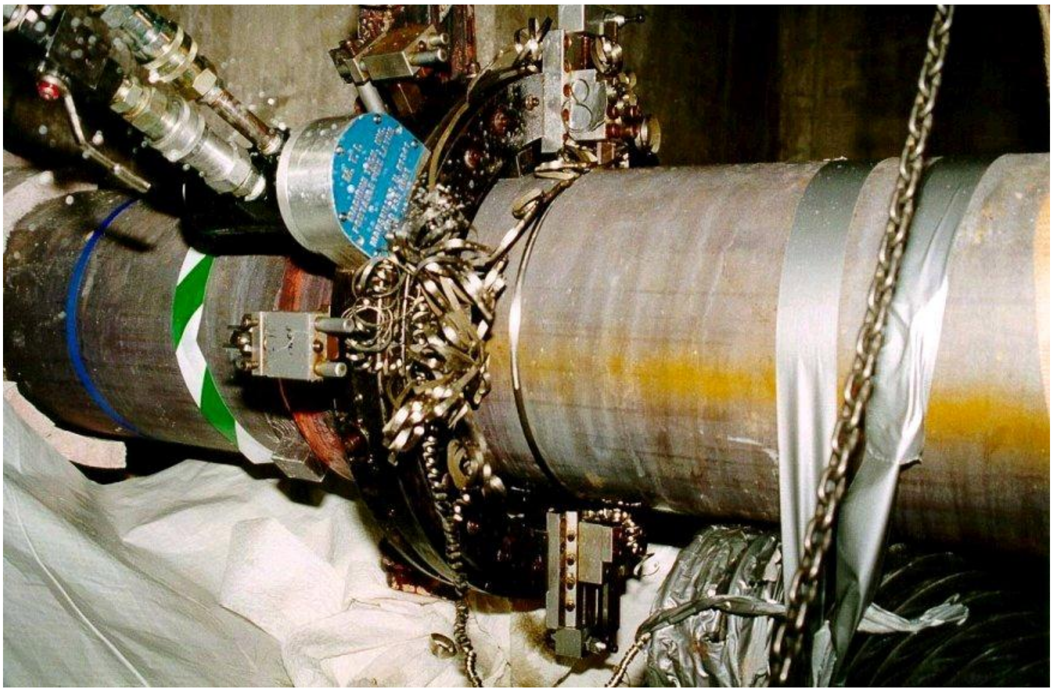

Figure 10. "Clam Shell" Pipe Cutter in Operation.

Clam Shell Cutters, or split frame pipe lathes as seen Figure 10 and Figure 11, are a reasonably inexpensive mechanical method for cutting large bore pipes. They are ideal for cutting highly radioactive pipes and reactor vessel nozzles, and produce a sufficiently good quality cut so that end caps or other features can be welded onto the cut pipe with minimal additional preparation.

From a radiological standpoint they are desirable since they are not surface destructive and do not generate the airborne radioactivity or fume associated with thermal cutting methods. They are also quickly installed and allow the operator to move away from the work piece during the cut, thereby avoiding unnecessary dose. The cutters require a radial clearance of 180 mm around the pipe to allow the cutting tool to move around the pipe and make the cut.

From a safety point of view, the cutters do not generate flames or applied heat, and therefore do not require a fire-watcher as part of the work team. They are also easy to use and quick to train operators in their use, compared to thermal cutting devices.

For decommissioning work in lower dose rate areas the clam shell cutters are less appropriate for thick components and do not cut as fast as plasma and oxy-fuel cutters. The overall time for each cut is longer than for hand held thermal cutters because of the set up time required.

Table 6 provides information regarding a High Speed Clam Shell Cutter from Tri-Tool.

Table 6. Information regarding Tri-Tool Inc. High Speed Clam Shell Cutter.

Item	**Tri-Tool Inc. High Speed Clam Shell Cutter**
Capacity/performance	250 mm to 1.22 m and above 16 min for 610 mm diameter cut 16-24 min dismantle/set up time between cuts
Secondary Wastes	Metal swarf

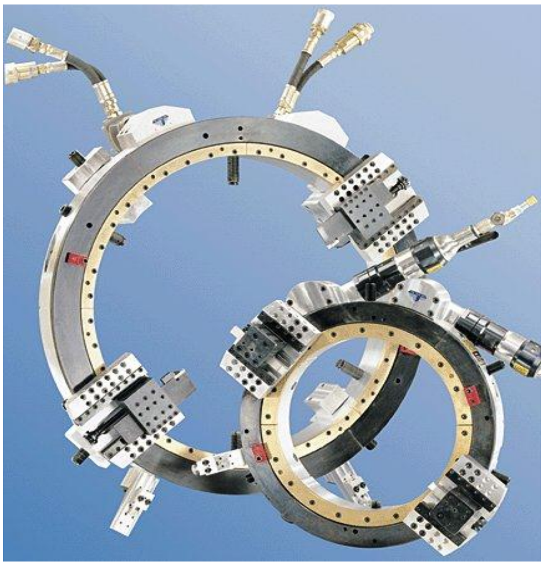

Figure 11. Manufacturers Photograph of Clam Shell Cutters.

4.4.2 Diamond Wire Saw

As an alternative to the Clam Shell Cutter, diamond wire saws can be used. These would be used in situations where contact working would not be advisable and there is either not enough space around the pipe to install a Clam Shell Cutter or where the pipe wall thickness is greater than the Clam Shell capacity.

The use of wire saws to cut metals is less common than for cutting concrete (see Section 4.10.1) and tends to be used in particular situations, e.g. when contact working is not preferred due to radiological conditions and the metal to be cut is beyond the capability of clam shell cutters. Because of this, and the fact that it is a relatively recent application of the wire saw technique, little comparative data is available.

4.4.3 Thermal Cutting

The thermal cutting techniques described above in Section 4.2.1.1 and 4.3.2.1 can also be applied to pipe work removal, in particular the use of hand-held or tracked plasma cutters.

Clearly, production rates will be highly variable depending on pipe size, and perhaps more importantly, the working conditions such as confined spaces, work at height etc. For larger pipe work sizes, oxy-fuel cutting tends to be more productive that plasma cutters though it produces more fume. Production rates of 0.65 man-hours per meter of pipe work have been reported for oxy-fuel cutting.

A Track Cutting System for Plasma or Oxy-Fuels is illustrated in Figure 12.

Figure 12. Track Cutting System for Plasma or Oxy-Fuels.

4.5 SMALL DIAMETER PIPE WORK

4.5.1 Mechanical Shears

A suitable tool for cutting of small-bore pipe work and other similar sized steel supports, uni-strut etc., is the Mechanical Pipe Shears. They were developed as an alternative to the more common reciprocating blade cutters. There are a number of different devices available.

The Mega-Tech Services Inc. Blade Plunging Cutter BPC-4, see Figure 13 and Figure 14, was used extensively during the decommissioning of the Big Rock Point BWR. It is a hydraulic power cutting tool capable of cutting ~75 mm pipe work and above. It has a 100 mm blade and is a piston-forced plunging cutter. The cutter weighs approximately 13 kg and is 710 mm long. It requires one operator.

It is powered by a trolley mounted Hydraulic Power Unit which powers the tool with an operating pressure between 344- 413 bar (5,000 - 6,000 PSIG). The Hydraulic Power Unit requires 3 phase 440V AC/ 20 amps, and it weighs 159 kg and can be located remotely from the cutter, for example, in a non-contaminated area.

Information regarding the Mega-Tech Blade Plunging Cutter is given in Table 7.The advantage of this type of cutter is that it offers a higher production rate than other methods of pipe cutting such as reciprocating saws. It also produces no secondary waste in the form of metal swarf or other cutting debris. It is also safer and quieter than other devices.

Its main disadvantage is that its weight makes it difficult to use above waist height (though it can be slung from a suitable support point and it can be hooked over the pipe being cut). Its weight also makes it heavy for continued use by the same operator.

The Mega-Tech Service Inc. machine is a mainly electric powered device. Battery powered models are also available through the battery increases the weight. The battery is typically worn on a belt.

Figure 13. Mega-Tech Services Inc. Blade Plunging Cutter.

Figure 14. Mega Tech Blade Plunging Cutter being used to cut 2.5 inch (6.35 cm) OD pipe.

Table 7. Information regarding Mega-Tech Blade Plunging Cutter BPC-4.

Item	**Mega-Tech Blade Plunging Cutter BPC-4**
Capacity/performance	Up to 75 mm pipe 46 sec for 50 mm cut 20 sec for 25 mm cut
Secondary Wastes	Spent cutting blades

4.5.2 Portable Saws

Portable reciprocating saws use the mechanical action of a hardened steel saw blade to cut metals. The major advantage of this type of tool is the absence of the fumes produced by thermal cutting. Saws are usually used for cutting soft metals such as carbon steel, aluminium or copper.

The saws can be operated by clamping them onto a work piece and using the weight of the device to advance it into the metal. Saws may be electric or pneumatically powered and can be set up to operate without operator assistance.

Portable powered hacksaws that can cut piping up to 300 mm in diameter are available. A 200 mm pipe can typically be cut in around 6 – 8 minutes; a simple rule of thumb is that such saws take a minute for each inch (2.54 cm) of pipe diameter.

4.6 OTHER STEELWORK

Other steelwork will generally be segmented using one or more of the thermal or mechanical techniques discussed above. The final selection will generally depend upon the location and size of the steelwork to be cut.

Some steelwork items may also be removed efficiently and safely by dismantling, particularly auxiliary structural items such as stairs and platforms that were originally assembled using bolts. Powered nut-runners such as those used in car workshops may be used to remove bolts quickly for disassembly. This does not reflect a need to remove these items intact but the fact that they may often be removed quicker and with less secondary waste in this way than by cutting them in situ.

In the case of surface contaminated steel work, sprayed coatings may be applied to fix contamination prior to dismantling in order to minimize generation of airborne contamination.

Production rates for steelwork removal have been reported as around 11 man-hours per tonne contaminated steel and 3.6 man-hours per tonne for clean material.

4.7 VENTILATION

Ventilation ducts etc. will be removed by unbolting (or disassembly appropriate to the duct construction) where the ductwork construction makes this possible.

Contaminated ductwork will be sprayed with contamination fixing spray coatings and then removed by unbolting the duct sections. The removed sections will then be crushed flat for packaging. The duct sections will only be cut where the size or geometry of the removed section makes it too big for packaging in the selected container. Where necessary, cutting will be carried out using shears or saws.

Clean or very lightly contaminated ducting may be cleaned by wiping if this will be sufficient to allow release. Other more aggressive techniques may be applied depending on the cost benefit and the availability of appropriate waste disposal routes.

4.8 CABLES ETC.

Segmented cables and cable trays etc. will be removed by first ensuring that the cable is safely isolated from the system and then segmenting it using heavy duty cable cutters (similar to bolt cutters) into lengths suitable for disposal as required. Even in relatively high contamination areas, plastic sheathed cables represent an opportunity for recycling of a relatively high value scrap material as the copper cable itself is protected by the plastic. Cable clips can be cut to release the cable from the tray, the cable can then be wiped to remove surface contamination and where this is successful the cut cable lengths can be offered for recovery of the copper. External steel armoured cables will be more difficult to handle so they would only be offered for recycling from non-radiological areas of the plant.

Automated copper cable recycling systems are available which are portable enough to be set up on site for a recycling campaign. These systems separate the plastic insulation from the copper and convert each into plastic and copper beads. An economic assessment would need to be done to determine the value of this option.

4.9 SURFACE CONCRETE REMOVAL

At various places within the power plant contaminated and possibly activated concrete will need to be removed for controlled disposal. It is generally not possible to clean contaminated concrete, so decommissioning projects make use of techniques which remove the contaminated concrete with a view to leave behind a clean structure suitable for demolition using conventional techniques.

It is expected that various concrete removal techniques will be required for the decommissioning project. These can be broken down into two main categories:

- Techniques that remove a surface layer of concrete (e.g. contaminated concrete) until the clean concrete beneath is revealed

- Techniques that remove bulk concrete, for example in the situation that contamination penetration is sufficiently deep so that the entire structure or a significant depth of contaminated or activated concrete must be removed.

This section will consider surface concrete removal with bulk concrete removal in the section immediately following.

There are a wide variety of surface concrete removal techniques available that have been deployed, with some degree of success, on a decommissioning project. In some cases the techniques have been adapted to provide both a fast technique suited to a wide-area and a smaller scale, slower technique for smaller areas or areas that wide-area techniques cannot reach, e.g. concrete removal close to embedded features.

4.9.1 Manual Techniques

Simple processes, such as brushing, washing and scrubbing, and vacuum cleaning, have been widely used since the need for decontamination/cleaning was first noted in the nuclear industry. These processes are generally labour-intensive and have the potential to increase worker dose, but they have the advantages of being versatile and leaving the concrete surface intact. They can be effective on very lightly contaminated concrete, concrete where the surface is very smooth and in good condition or on painted/epoxy coated concrete. In some cases they may remove the majority of the contamination leaving only some smaller areas requiring mechanical decontamination using either a simple abrasive grinding wheel or a manually operated version of one of the techniques described below.

They are also used as the first step (e.g. to vacuum dust and remove loose contamination) before or during dismantling, to prepare items for more aggressive decontamination using stronger mechanical processes as they reduce the potential for airborne contamination during those aggressive techniques.

4.9.2 High Pressure Water Washing

This technique, also known as Hydro lazing, involves directing high-pressure water at the surface being decontaminated. Typically, the equipment is a hand held lance supplied by pumps delivering water at pressure; the pressure being dependent on the exact type of equipment used but typically between 3 500-350 000 kPa (35-3500 bar). The technique is suitable for removal of surface or near surface contamination, in particular where the surface is inaccessible to the manual techniques above or is too large for the manual techniques to be easily or economically applied.

The technique does produce secondary waste in the form of the water used. The water needs to be retained by temporary bunds and collected for controlled disposal or cleaning to remove any solid material it has picked up. Typically for every 1 000 litres of water used, 1 litre of solid material will be produced. As an additional precaution against spread of activity, the area for the pressure water washed concrete should be isolated from the surrounding area by screens or other enclosure.

4.9.3 Scabbling

Scabbling is a scarification process used to remove concrete surfaces. Scabbling tools typically incorporate several pneumatically operated piston heads striking (i.e. chipping) a concrete surface. Available scabblers range from one to three headed hand-held scabblers to remotely-operated scabblers, with the most common versions incorporating three to seven scabbling pistons mounted on a wheeled chassis. Scabbling bits have tungsten carbide cutters, the bits having an operating life of about 80-100 h under normal use. Both electrically and pneumatically driven machines are available. Because scabbling may cause a cross-contamination hazard, vacuum attachments and shrouding configurations have been incorporated. According to the claims of at least one manufacturer, this enables scabbling to take place with no detectable increase in airborne exposures above background level, though filtered and ventilated enclosures can be used if airborne contamination is likely to be produced.

In practice, large area floor scabblers may only be moved to within some 50 mm of a wall. Other hand-held scabbling tools are therefore needed to remove the last 50 mm of concrete flooring next to a wall, as well as remove surface concrete on walls and ceilings.

Scabbling is a dry decontamination method – no water, chemicals or abrasives are required. The waste stream produced is only the removed debris. Work rates vary widely because of variations in concrete composition and characteristics, depth of contamination, as well as to the different types of bits that may be used. Typical removal rates against depth are shown in Table 8.

Table 8. Variation of Scabblers Production Rates with Depth.

Removal Depth (mm)	Production Rate (m^2/h)
4.25	2.78 – 3.72
6.35	1.30 – 2.23
12.70	0.65 – 1.12
25.40	0.28 – 0.56

Scabblers are best suited for removing thin layers (up to 15 or 25 mm thick) of contaminated concrete (including concrete block) and cement. It is recommended for instances where:

- Airborne contamination should be limited or avoided
- The concrete surface is to be reused after decontamination
- Waste minimization is envisaged
- The demolished material is to be cleaned before disposal

The scabbled surface is generally flat, although coarsely finished, depending on the cutting bit used. This technique is suitable for both large open areas and small areas.

The techniques can be applied to floors and walls, though the requirement to have a reaction force if the equipment is to be effectively used on walls often results in additional equipment requirements, e.g. hydraulic arms to hold the equipment in place.

Figure 15. PENTEK Moose® Remotely Operated Floor Scabbler.

Figure 15 shows a proprietary remotely operated floor scabbling device, in this case the Pentek Moose system. This is typical of devices on the market. It can scabble between 25 40 m^2/h at a concrete removal depth of 1.6 mm (slower at increased removal depths, e.g. 12.1 m^2/h for 3.2 mm demonstrated at Argonne National Labs) and scabbles a 450 mm wide strip. It uses 7 tungsten carbide tipped 57 mm diameter scabbling heads, as shown in Figure 16.

Figure 16. View of underside of PENTEK Moose cutting head.

As it can only reach to within 150 mm of walls other smaller devices are used to scabble areas that have not been cleaned by the larger machine. These smaller devices will typically be wheeled 3 head devices capable of scabbling a 150 mm wide strip at 1.8-2.8 m^2/h for a removal depth of 1.6 mm. Slightly wider 5 head machines are also available. For obstructions and other features that cannot be removed hand held, single head scabblers are available.

Similar machines are available for use on hydraulic arms or frames for scabbling walls.

4.9.4 Needle Scaling

Needle scalers are usually pneumatically driven and use uniform sets of 2, 3 or 4 mm needles to obtain a desired profile and performance. Needle sets use a reciprocating action to chip contamination from a surface. Most of the tools have specialized shrouding and vacuum attachments to collect removed dust and debris during needle scaling with the result of no detectable increase in airborne dust concentrations above normal levels.

Needle scalers are an excellent tool in tight, hard-to-access areas (e.g. pipe penetrations, corners etc.), and may also be used for wall and ceiling surface decontamination. This technique is a dry decontamination process and does not introduce water, chemicals or abrasives into the waste stream. Only the removed debris is collected for treatment and disposal. Production rates vary depending on the desired surface profile to be achieved. Nominal production rates vary between 1.8-2.8 m^2/h for 1.6 mm removal depth using a 44.5 mm wide cutting head (based on Pentek Corner Cutter needle gun).

4.9.5 Concrete Shaving

A Concrete Floor Shaver is similar in appearance to a wheeled Scabbler. It has a quick-change diamond-tipped rotary cutting head designed to give smoother surface finish than a scabbler, easier to measure and ready for painting. It is capable of cutting through bolts and metal objects, which would have damaged the cutting head of a traditional scabbler. Actual cutting performance results in:

- A higher mean working rate for floor decontamination compared to scabbling;

- Much less physical load on the operators due to the absence of machine vibration.

The Marcrist Floor Shaver and the resulting floor surface are illustrated in Figure 17.

Figure 17. Marcrist Floor Shaver and the resulting floor surface.

The concrete shaver consists of the following components:

- A 250 mm wide 127 mm diameter shaving drum into which diamond impregnated blades are fitted. The number of blades is dependent on the required surface finish

- An extraction port for use with a vacuum extraction unit for dust-free operation

- A manual rotary wheel depth control with electronic display

The machine can also be fitted onto hydraulic arms for shaving walls (see Figure 18).

Figure 18. Floor Shaver mounted on Brokk 250 for wall decontamination.

Based on the positive experience with the floor shaver a remote controlled diamond wall shaving system has been developed as a solution for concrete decontamination of larger surfaces. The system consists of:

- A remote-controlled hydro-electric power pack for the remote-controlled shaving unit
- A vacuum system to fix temporarily vacuum pads holding the horizontal and vertical rails of the shaving head
- A simple xy-frame system containing a guide rail, a vertical rail and a carriage for the shaving head
- A quick-change diamond-tipped rotary shaving head with dust-control cover for connection to existing dust-extraction systems

The entire system is built up in sections, which are portable by one operator. It removes a concrete layer in a controlled and vibration-free manner with the removal depth being controllable between 1 and 15 mm per pass, producing a smooth-surface finish. The cutting head is designed to follow the contours of the surface being removed, and depth adjustments may be set manually in increments of 1 mm to minimize waste production. With 300 and 150 mm wide shaving heads available, both large areas and awkward corners may be accessed.

When the vertical rail is fitted to the wall with the cutting head shaving, the horizontal rail may be disconnected and moved forward, thus ensuring continuous operation.

Production rates vary depending on the structure and the hardness of the concrete, the depth setting, the cutting speed and the type of diamond used. Heads can be used for shaving up to 2000 m^2.

4.9.6 Summary

Table 9 provides summary data (where readily available) for the various techniques for surface concrete removal described above.

Table 9. Summary data for surface concrete removal.

Technique	**% Contamination Removed or Layer Thickness removed (mm)**	**Production Rate (m^2/h) (machine working time)**	**Operating Resources**	**Secondary Waste Produced**
Manual Techniques	~20% Nil layer removed	2.8	2 labourers	Cloths etc. 0.005 m^3/h or 0.014 m^3/m^2
High Pressure Water washing	~25% for hard to remove contamination. Higher for loose surface contamination.	Up to 34	1 operator 2 labourers	Water 0.05 m^3/h or 0.0054 m^3/m^2
Floor/Wall Scabbler – manually operated (1 head)	1.5 mm	1.13	1 operator	HEPA Filters for dust vacuum system, removed concrete dust
Floor Scabbler – Manually operated (5 Heads)	3 mm	2.5	1 operator	HEPA Filters for dust vacuum system, removed concrete dust
Floor Scabbler – Remote Controlled (7 heads)	3.1 mm	12.1 (plus 2.5 h set time per location)	2 operators	HEPA Filters for dust vacuum system, removed concrete dust
Wall Scabbler (3 heads)	3 mm	4.6	-	HEPA Filters for dust vacuum system, removed concrete dust
Needle Scaler	1.6 mm	1.8 – 2.8	1 operator	HEPA Filters for dust vacuum system, removed concrete dust
Floor/Wall Shaver	3 mm	11.9	1 operator	HEPA Filters for dust vacuum system, removed concrete dust

4.10 BULK CONCRETE REMOVAL

In cases where a significant depth of concrete has become activated or contamination has penetrated deep into the thickness of a concrete structure, e.g. a reactor biological shield, the entire concrete structure is removed. A number of techniques are available for this as described below.

4.10.1 Diamond Wire Saw

Diamond wire saw cutting is used to remove concrete, particularly reinforced concrete, as blocks, see Figure 19. This technique is particularly suitable if concrete needs to be removed cleanly, perhaps to generate access, or with minimal airborne contamination. A cart mounted unit drives a wire that carries diamond impregnated beads. Typically, three or four beads are held in place by springs mounted between smaller, fixed beads. There are approximately forty 11 mm diameter beads per meter of wire. Wire saws are good at cutting through concrete with metal embedment, such as reinforcing bars, provided the material to be cut is solid (no voids or sections that can move during the cutting operation).

For cutting of large structures, the wire is threaded through holes drilled into the structure of approximately 50 mm diameter. For smaller structures the wire can be passed completely around the structure. There is no real limit to the depth of cut that can be achieved other than that determined by other practical factors such as the routing of the wire blade, the positioning of equipment or the ability to lift the removed pieces.

The cutting requires the introduction of water to act as both a dust suppressant and also as a lubricant for the blade. The resulting water/concrete dust mixture is a secondary waste that requires management. In the case of activated/contaminated concrete cutting, systems can be established to collect, filter and recycle the majority of the water used during the cutting.

Wire sawing techniques are also useful if removal of large components requires the removal of all or part of any surrounding concrete missile shields or biological shield walls.

Table 10 provides information regarding a Diamond Wire Saw Cutter.

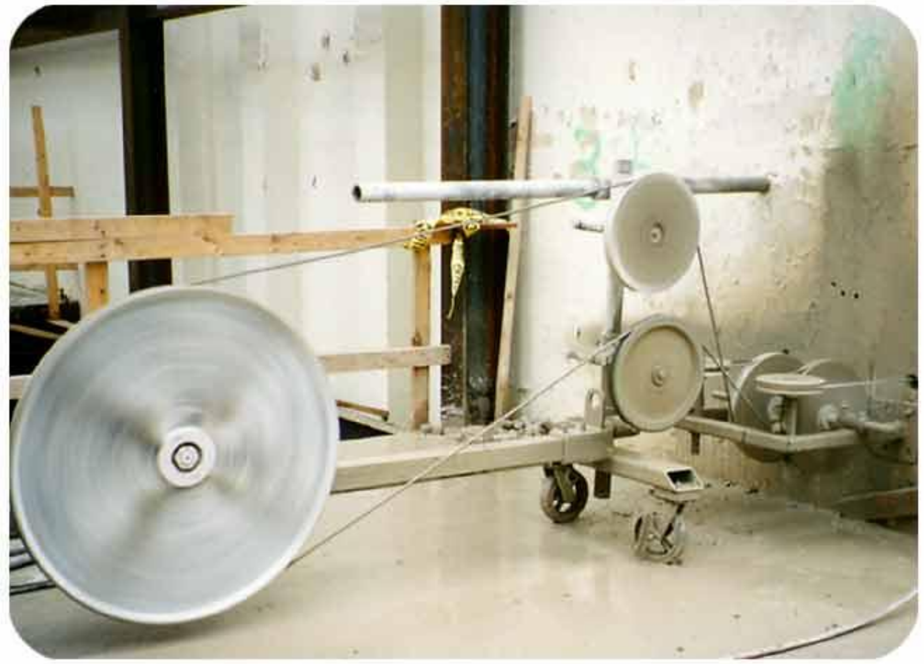

Figure 19. Typical Wire Saw drive in action cutting a section of wall.

Table 10. Information regarding the Diamond Wire Saw Cutter.

Item	**Diamond Wire Saw Cutter**
Capacity/ performance	– No real limit other than that set by the practicality of equipment positioning, wire routing etc. – Drilling of 50 mm diameter holes for wire saw blade access = up to 1.0 m per hour per unit – Approximately 2 hours to set up wire saw equipment for each cut – Wire sawing up to 1.0 m^2 per hour
Secondary Wastes	– Slurry consisting of cooling/lubricating water and concrete debris – Water flow rate for wire sawing = 10-15 litre/min – Spent saw blade consumed at approx. 1 m wire per 0.5 m^2 of cut

As an alternative to water as a blade coolant, liquid gases have been used in trials. However, these techniques are not as widely available and are not effective at suppression of dusts, which is expected to be an important issue in a nuclear power plant decommissioning project.

4.10.2 Impact/Crushing Techniques

For situations where the care and precision of diamond wire sawing is not required, conventional demolition techniques can be used, such as impact and crushing techniques. These techniques use a combination of impact hammers (jackhammers or pneumatic drills) and concrete breaking jaws, typically mounted on small excavators of Brokk demolition machines, see Figure 20-Figure 22.

The impact hammer usually has a chisel point and impacts the surface to be removed at rates of up to 600 blows per minute delivering up to 2 700 Nm force per blow. The technique has been used extensively on many decommissioning applications largely because of its versatility and low cost.

Concrete breaking jaws can also be used where there is suitable access to the edge of a wall to allow the jaws to work.

There are issues of noise pollution and dust generation, which can lead to airborne contamination, to be considered when using these techniques. The impact on personnel can be mitigated through the use of suitable personnel protective equipment and the use of water mist/sprays to reduce dust.

Figure 20. Brokk 330 demolition machine equipped for concrete breaking.

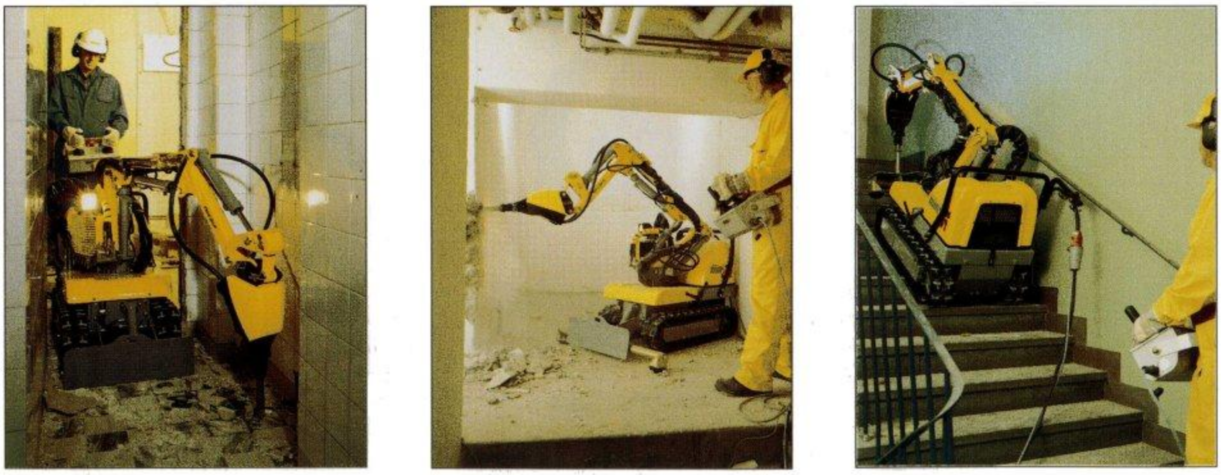

Figure 21. Brokk Demolition Machine (Model 40) equipped for remote control impact demolition.

The production rates achievable using concrete breaking hammers and jaws are highly variable depending on issues such as accessibility and radiological conditions.

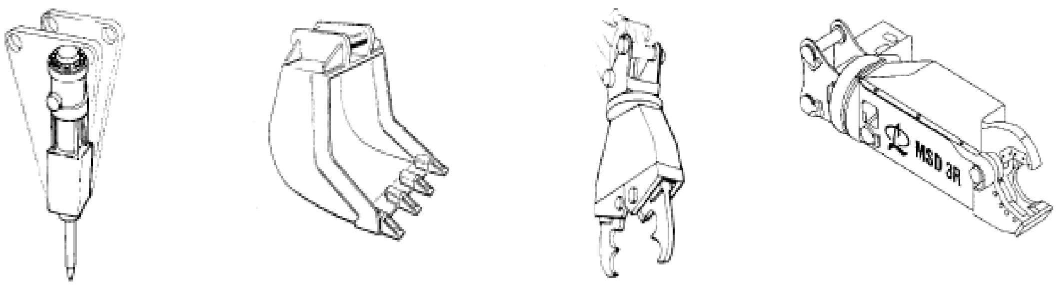

Figure 22. Examples of tools for use with demolition machines.

Table 11 provides information regarding the "Brokk" type remote controlled Demolition Machine from Brokk.

Table 11. Information regarding the "Brokk" type remote controlled Demolition Machine.

Item	**"Brokk" type remote controlled Demolition Machine**
Manpower Requirements	1 Equipment operator
Capacity/performance	Able to remove walls up to 0.9 m thick (3 feet) using Brokk mounted equipment. Larger scale equipment can handle greater thicknesses. Production rate is highly variable but during monitored trials an average rate of 4.5 m^3 per day was achieved using a Brokk 150 removing a reinforced concrete structure up to 3 feet thick.
Secondary Wastes	Misc. operating wastes such as hydraulic hose, wipes etc.

4.11 DEMOLITION

It is intended that all buildings, both contaminated and clean, are demolished using similar techniques. Contaminated buildings will be cleaned and surveyed as such and then demolished using conventional techniques appropriate to the building size and construction method.

Buildings will be stripped out of easily removed recyclable material. High level glass will also be removed as a safety measure. Concrete and brick buildings will be demolished using machine (excavator) mounted concrete crushers, breakers and grabs, with water spray applied where necessary to reduce creation of dust; which in this case would only be a conventional rather than a radiological hazard. The resulting debris will be crushed and metals separated out at this point. Concrete waste will be used as infill of below ground voids or transported off site as required.

Steel frame buildings represent an opportunity for relatively easy metals recycling and these will be demolished using mobile cranes, machine excavators and thermal/mechanical cutting tools.

Explosive demolition techniques may offer a safer demolition option on some taller structures, but may not be acceptable due to the presence of other nearby facilities.

History

Review and approval status (Organization, name)

Rev No	Prepared	Reviewed	Approved	Date
				Month dd, yyyy

Revision record

Rev No	Section	Cause

APPENDIX 1

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APPENDIX 2

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